STRATFORD/AVON RIVER ENVIRONMENTAL MANAGEMENT PROJECT

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MANAGEMENT PROJECT

DESIGN OF AN ARBOREAL SHADE PROJECT TO CONTROL AQUATIC PLANT GROWTH

Technical Report No. S-15

Prepared by:

D. Hayman,
M. Fortin,
M. Seto

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PREFACE

This report is one of a series of technical reports resulting from work undertaken as part of the Stratford-Avon River Environmental Management Project (SAREMP).

This two-year Project was initiated in April 1980, at the request of the City of Stratford. The SAREMP is funded entirely by the Ontario Ministry of the Environment. The purpose of the Project is to provide a comprehensive water quality management strategy for the Avon River Basin. In order to accomplish this considerable investigation, monitoring and analysis have taken place. The outcome of these investigations and field demonstrations will be a documented strategy outlining the program and implementation mechanisms most effective in resolving the water quality problems now facing residents of the basin. The Project is assessing urban, rural and in-stream management mechanisms for improving water quality.

This report results directly from the aforementioned investigations. It is meant to be technical in nature and not a statement of policy or program direction. Observations and conclusions are those of the authors and do not necessarily reflect the attitudes or philosophy of agencies and individuals affiliated with the Project. In certain cases the results presented are interim in nature and should not be taken as definitive until such time as additional support data are collected.

Enquiries with respect to this report should be directed to:

Ministry of the Environment
985 Adelaide Street South
London Ontario
N6E 1V3
(519) 681 3600

ABSTRACT

Shading of the Avon River with trees has been considered as one means of controlling the growth of nuisance aquatic plants during the summer months. The design of a shade tree planting project is considered in this report. Tree species considered here are black willow, silver maple and poplar, all of which are suited to bottom land growing conditions.

It is shown that tree planting may prove very effective in limiting light that reaches the river. Other possible impacts include reduction of water temperatures and a reduction of dry weather flows. Planting costs are about $2000 per kilometer. Fencing and the possible need for land easements may each add $8000 to this figure.

Flooding and ice scour are considered to be serious hazards to the successful establshment of trees. These factors likely mean that planting must be gradual starting in areas where natural protection from ice is currently available.

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1. INTRODUCTION

The use of a grove of deciduous trees is being considered as a means of improving water quality on the Avon river. The bank-side trees are intended to intercept sunlight that now reaches the river and will thereby limit photosynthetic activity and thus reduce the nuisance aquatic plant growth that occurs. This shading may also reduce water temperature during the day. This report outlines design details and explains the calculations that were made to measure the impact of tree shading on incident sun light, water temperature and drought flows.

2. PROJECT DESIGN

The planting design involves a mixture of species in order to provide a robust and aesthetically pleasing plant community. Black willow (*Salix nigra*), silver maple (*Acer saccharinum*) and carolina poplar (*Populus* sp.) were chosen for their rapid growth rate and tolerance to wet growing conditions on bottom land. A gradual approach to planting will be necessary to minimize failures caused by ice damage and high flows. This approach would entail planting first in areas where existing trees or high banks afford some protection to new seedlings. Plantings in other areas can poceed only as protection to seedlings can be provided.

Black willow cuttings would be planted at 2.1 m intervals immediately adjacent to the stream.* This species has been observed to grow to 32.7 m in height with a canopy radius of up to 15.0 m (Table 1). The next row, planted 3 m back, would be comprised of silver maple. These trees grow to a height of 26.1 m with a canopy radius of up to 11.5 m (Table 1). An outer row of carolina poplar, planted a further 3 m back, would provide early protection for the other rows of trees and some early shade since they grow so quickly.

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* Planting dimensions noted here are preliminary and may require further refinement. Specific values are assumed to facilitate costing.

TABLE 1: FIELD OBSERVATIONS FOR SHADE TREES GROWING ON RIVER BANKS

CHARACTERISTIC	Black Willow (Salix nigra)			Maple* (Acer spp.)		
	min.	mean	max.	min.	mean	max.
Light penetration under the canopy and above the water's surface (%)						
- full leaf development	2.0	26.6	78.1	2.3	17.7	39.2
- early spring (May 11)	15.3	36.0	45.8	61.5	70.8	76.9
Light penetration under the tree canopy and just below the water's surface with full leaf development (%)	1.3	12.6	31.3	1.5	12.2	32.5
Tree height (m)	12.0	21.5	32.7	9.7	17.4	26.1
Canopy diameter (m)	12.3	19.1	29.0	7.0	11.7	22.8
Distance from channel edge (m)	4.0	9.3	18.3	1.5	6.1	11.8
Portion of canopy that extends over the channel (%)	27.7	51.1	74.2	14.0	50.8	85.3
Number of trees used for the "full leaf development "observations (all mature)		15			9	
Number of height observations		16			8	
Number of light observations		23			27	

* Maples did not tend to occur naturally along the river banks.

3. HABITAT DESCRIPTION

3.1 River

The Avon River, oriented in an east-west direction, is approximately 16.5 km in length from station 7 to its mouth (Figure 1). Stream widths range from 7.4 to 31.0 m with a weighted average width of 17.3 m (Figure 2).

3.2 Topography

Aerial photographs and field observations indicate land adjacent to the stream banks had a shallow slope ($0\text{-}5^{o}$) for over 50% of the river length; a moderate slope ($5^{o}\text{-}20^{o}$) for 35% of the length while the remaining 15% was steeply sloped (Figure 3).

3.3 Soils

In the vicinity of the Avon River, soil composition is classified as poorly drained bottom land. This consists of outwash gravels and alluvial deposits.

3.4 Land Uses

Almost 500 pastured dairy and beef cattle have access to approximately 10.0 km of the river below Stratford (Hayman 1983). This includes 1.0 km of river where woodlands are pastured. A further 1.5 km of the river is bordered by unpastured woodland. Unused land or pastures generally act as buffer strips between the river and crops; however, for approximately 0.5 km, the river is within 10 m of cropland.

3.5 Stream Flows

Modelling analysis of flood flows on a lower reach of the river indicated that typical annual flood flows increase the water level by about one meter and that the 100 year flood might increase water

FIGURE 1: MAP OF THE AVON RIVER SHOWING WATER QUALITY MONITORING STATIONS

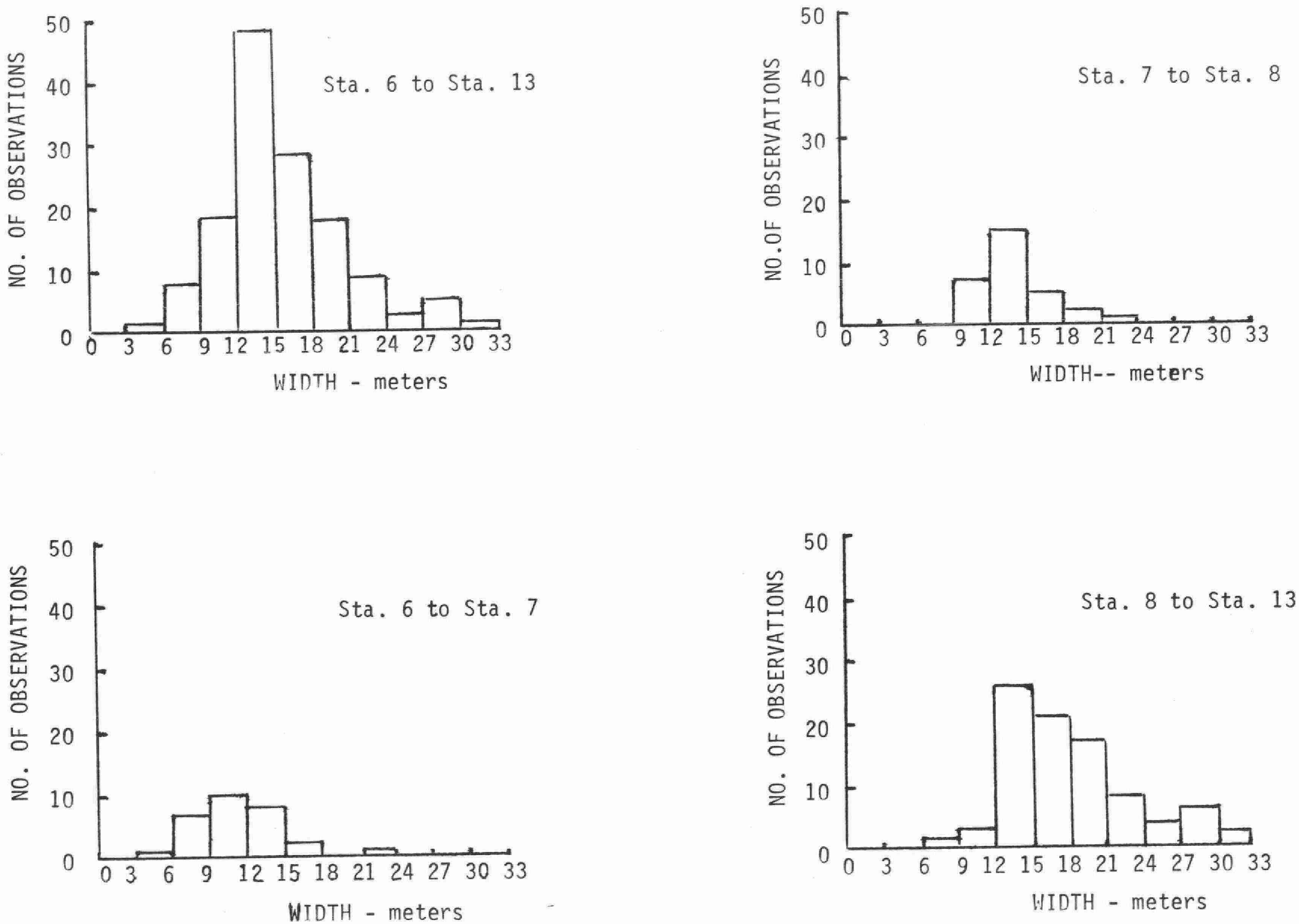
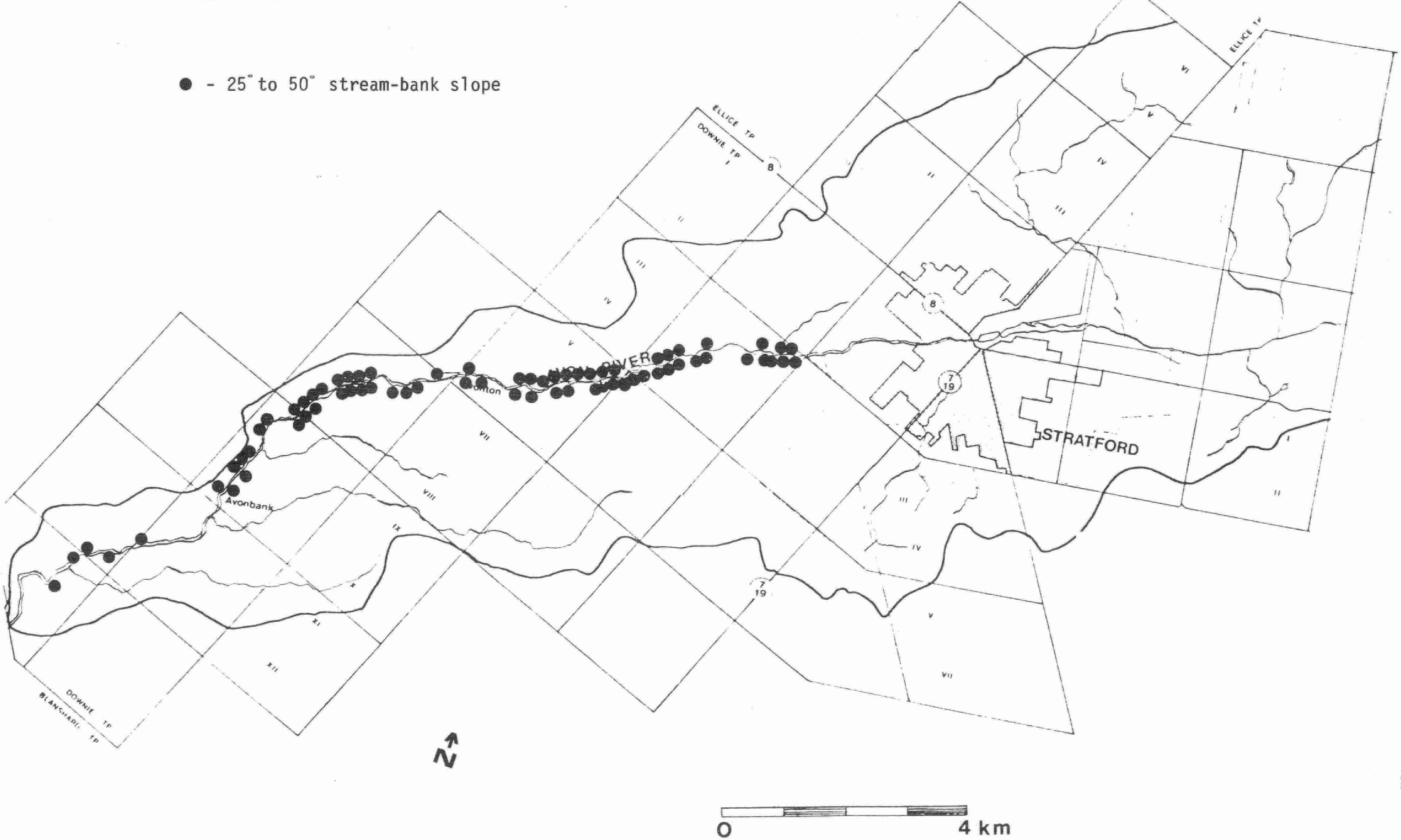


FIGURE 2: HISTOGRAMS DESCRIBING STREAM WIDTH ON THE AVON RIVER

FIGURE 3:: LOCATION OF STEEP RIVER BANKS

● - 25° to 50° stream-bank slope



levels by 3 meters (Seto 1981). While these exact flood levels will not prevail elsewhere on the river because of different channel characteristics, they are nevertheless indicative of the stress that seedlings will face during flooding episodes.

The mean summer dry weather flow in 1981 was 0.35 $m^3\ sec^{-1}$. The estimated minimum 7-day mean flow observed over a 20 year period (the $7Q_{20}$ flow) is 0.06 $m^3\ sec^{-1}$ at the federal flow guage - GD018 (Fortin, Seto, 1981).

4. REFORESTATION CONSIDERATIONS

Tree planting along a floodplain poses some unique problems for successful tree establishment.

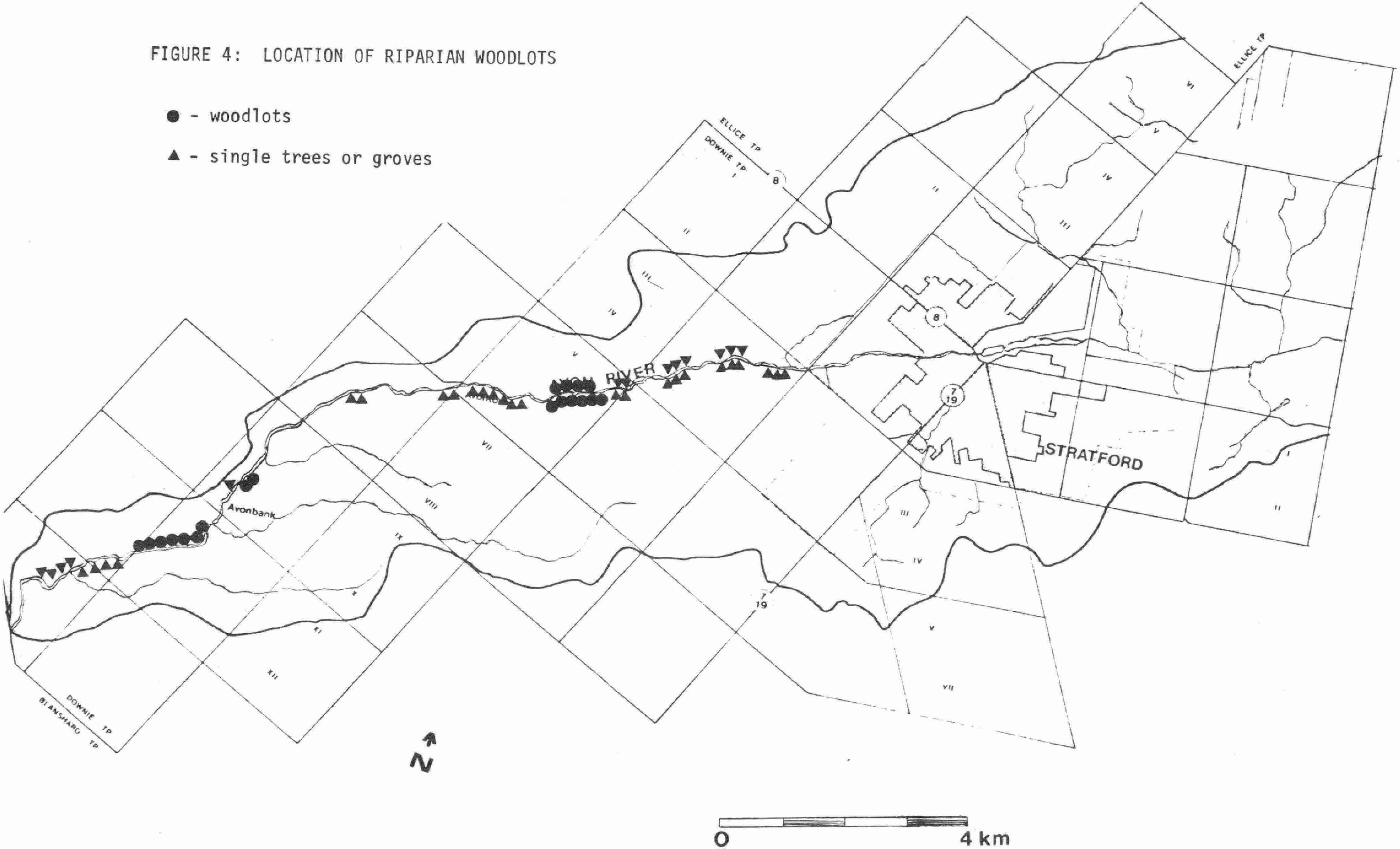
Assuming a water level increase of 1 m, flood water would completely inundate approximately 60% of the banks. These flood waters, in association with ice, could cause a high failure rate among black willow and silver maple seedlings. To reduce this failure rate, it may be necessary to plant trees higher up on the river bank planting closer to the stream only if additional protection can be provided. This may be a required planting strategy for approximately 50% of the stream's length. Elsewhere, the river banks could be planted from the outset since adjacent woodlots and steeper banks already provide protection for seedlings.

Seedlings in a cattle pasture would have a high failure rate due to trampling and grazing. Fences might therefore be needed along the 10 km of stream accessible to cattle. In these cases, limited access sites or alternative watering supplies would have to be provided. Provision should be made to protect fences from ice damage and to ensure a ready access corridor along the river to facilitate forestry activities.

FIGURE 4: LOCATION OF RIPARIAN WOODLOTS

● - woodlots

▲ - single trees or groves



Rodents and competition from weeds will also lower seedling success rates. There are a number of effective rodenticides and herbicides currently on the market. However, the application of these chemicals near the water may lead to contamination of the river, and a very cautious chemical control program would therefore be required. Alternative methods such as raptor posts for control of rodents might be worth consideration.

5. ENVIRONMENTAL IMPACT

5.1 Impact on Incident Sunlight

The Avon river runs largely east to west. Therefore shading is mainly a result of the overhanging tree canopy. Where the canopies from opposite banks fail to completely span the river, a portion of the main channel may remain in full sunlight.

Spurr (1964) states that light penetration under a mature deciduous forest canopy may be 1 to 5% in summer, while a coniferous forest will allow a 10 to 15% penetration of light. Since these figures are not necessarily representative of trees growing in open areas, field observations were made on shade trees already established along the river bank. These indicated that black willow and maple will allow an average 18-27% light penetration (Table 1).

Using these values, the percent shade cover expected (P) can be estimated as (Quigley, 1981):

$$P = (100/w) \times T \times (\tan Z) \times (\sin\ A-R\ ) + (Y - c/2) \qquad (1)$$

where:

W =	average stream width	
Y =	average vegetation to stream distance	
R =	stream orientation	
T =	tree height	
Z =	zenith angle where $\cos(Z) = \mathrm{sim}(L)\ \sin(d) + \cos(L)\ \cos(d)\ \cos\ (h)$	
L =	latitude	

d = solar declination

h = hour angle of sun

A = azimuth angle where $\sin(A) = \frac{\cos(d)\ \sin(h)}{\sin(z)}$

C = crown measure

This equation assumes the tree crown is centered over its trunk. However, field observations suggest black willow lean towards open areas above the stream channel. Although these trees were, on average, 9.3 m from the streams edge, greater than 50% of their canopy extended over the water (Table 1). Therefore the percent surface shade is calculated as:

$$P = (100/w) \times T \times (\tan Z) \times (\sin\ \ A\text{-}R\ ) + O$$

where O is the observed overhang distance (m) taken from Table 1 data.

Due to the variation in stream width and changes in stream orientation, the river has been divided into three separate reaches: water monitoring stations 7-8, 8-10 and 10-13. Using the weighted average solar declination from May to September, 15.6^{o} (Quigley 1981) the average daily percent shade cover was calculated based on trees growing along both banks to a height of 12 m and 32.7 m.

Provided assumptions regarding tree growth are accurate, results in Table 2 indicate that a large area of the stream can be shaded throughout most of the day.

5.2 Impact on Water Temperature

There is some evidence that mean daily water temperatures are determined by the sequence of antecedent inputs of solar radiation (Fortin, 1982). This effect may result from the smoothing action of thermal energy sinks such as Lake Victoria in Stratford and the surrounding land mass. On the other hand, strong evidence indicating that maximum daily water temperatures are affected by daily solar radiation inputs is provided by Barton and Taylor (1981). They developed a relationship between maximum water temperature and

TABLE 2: PERCENTAGE AREA OF THE STREAM THAT IS SHADED DURING THE GROWING SEASON

Time of Day	Hour Angle (h^o)	% Shaded Area by Reach*: Stn. 7-8 min.	Stn. 7-8 max.	Stn. 8-10 min.	Stn. 8-10 max.	Stn. 10-13 min.	Stn. 10-13 max.
800	-60	100	100	98	100	100	100
900	-45	100	100	98	100	100	100
1000	-30	100	100	96	100	100	100
1100	-15	100	100	93	100	94	100
1200	0	100	100	88	100	80	100
1300	15	100	100	83	100	66	83
1400	30	95	100	75	100	63	76
1500	45	80	98	63	77	86	100
1600	60	84	100	66	85	100	100
1700	75	100	100	94	100	100	100
Mean % Coverage	-	96	100	77	96	89	96
Duration of Partial Shade (hours)	-	3	1	10	2	5	2

* Minimum corresponds to a tree height of 12 m and maximum to a tree height of 32.7 m (see Table 1).

the presence of riparian tree cover that suggests a temperature reduction rate of 5.8^{0}C per kilometer of riparian forest at a distance of one kilometer into a forested reach (their relationship is non-linear, declining with buffer strip length).

These two seemingly contradictory findings imply that a complete model of water temperature must include both long term energy inputs and day-to-day variations of solar radiation in order to describe seasonal trends and diurnal fluctuations. The need for analysis of water temperatures in SAREMP did not warrant such an exhaustive modelling effort. Consequently, the following simplifying assumptions were made:

(a) Minimum daily temperature is determined by long term energy inputs as measured for instance by a moving average of antecedant daily total solar radiation (Fortin, 1982). It will not be affected by shading.

(b) The amplitude of the diurnal water temperature cycle is determined by daily solar radiation.

(c) The amplitude of the diurnal water temperature cycle will respond to reductions in daily solar radiation caused by tree shading or by cloud cover in a similar manner.

The last assumption, which is admittedly approximate at best, was made in order to enable us to use observed Avon River data to relate daily solar radiation to water temperature variations. This relationship, estimated by least squares regression, is given in equation (2)*:

$$(t_{max} - t_{min}) = \underset{(4.171)}{2.254} + \underset{(6.488)}{11.084}S \qquad (2)$$

$r^2 = 36.26$, F-score = 42.10, sample size = 76.

*t-scores for estimated coefficients are given in brackets.

In this equation, S designates mean daily solar radiation as Langleys m^{-2} minute $^{-1}$, and $(t_{max} - t_{min})$ measures the amplitude of the diurnal cycle (^{o} Celsius).

The correlation coefficient is low even though test statistics are all significant at a 1% level. This confirms the fact that we are using overly simplified models to approximate a complex process.

Equation (2) results were used to estimate a relationship between shading and daily water temperatures evaluated at their means over the period of full leaf (June to September). The diurnal temperature amplitude estimated at the mean level of solar radiation observed in 1980 (.3 Langleys m^{-2} minute^{-1}) was 5.7^{o}C, while the mean of observed values was 5.3^{o}C (see Table 3). At these mean values the impact of shading on incident daily solar radiation can be expressed at the product of L and S where L is the percentage light penetration variable. For the shading schemes being considered in this report, estimates of L range between .02 and .78 with a value of .27 being a likely outcome (Table 1, black willow). With a light penetration value of 27% the diurnal temperature amplitude becomes 3.2^{o}C.

TABLE 3: METEOROLOGIC DATA FOR THE AVON RIVER

Variable	Mean Value	Maximum Value	Minimum Value	Standard Deviation	Sample Size
Water Temperature ^{o}C					
Mean Daily	20.8	26.5	7.9	4.1	92
Maximum Daily	23.5	30.1	9.9	4.2	92
Minimum Daily	18.2	24.6	5.1	4.5	92
Daily Range	5.3	10.8	1.4	2.1	92
Air Temperature ^{o}C					
Mean Daily	17.8	24.4	6.4	4.2	121
Sunlight - Langleys $m^{2}S^{-1}$					
Mean Daily	.31	.53	.05	.12	105

The current daily mean water temperature, 20.8°C, would fall by one half the change in the diurnal temperature range to 19.7°C (see Figure 5)*.

The mean of daily maximum water temperatures observed in the Avon River was 23.5°C. Given the assumption made above, shading that results in a 27% light penetration would lower this mean to 21.4°C, (i.e. by the amount of the change in the diurnal temperature amplitude). In comparison to their predicted value, the model developed by Barton and Taylor (Pg. 17) predicts a mean value for daily maximums of 21.7°C for an aboreal buffer strip 2.5 kilometers long and 20 meters wide **.

The agreement here is quite close despite the fact that Barton and Taylor exclude streams like the Avon - shallow with an east-west alignment - from the sample they use for estimation purposes. The one stream in their data set with these characteristics, Galt Creek, is largely forested and has a mean maximum daily water temperature of 21.4° Celsius. The agreement of this value with our predicted Avon value is reassuring.

5.3 Impact on Drought Flows

Black willows, when planted by the stream can obtain water directly from the water table (phreatrophy). Under wet conditions, an average mature phreatrophyte will transpire 45,460 l (10,000 gallons) in a single growing season. Under the mixed planting strategy there could be over 15,700 black willow along the river banks. The total evapotranspiration could therefore be 7.14×10^8 l between May and

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* This assumes that the diurnal water temperature cycle is symetric about the mean daily temperature and that the minimum daily temperature doesn't change (see assumption (a) above).

** See the last equation on Pg. 17 of their report. The 2.5-kilometer length used here is an estimate made by Barton and Taylor of the maximum effective buffer strip length for lowering water temperature (Pg. 12-14).

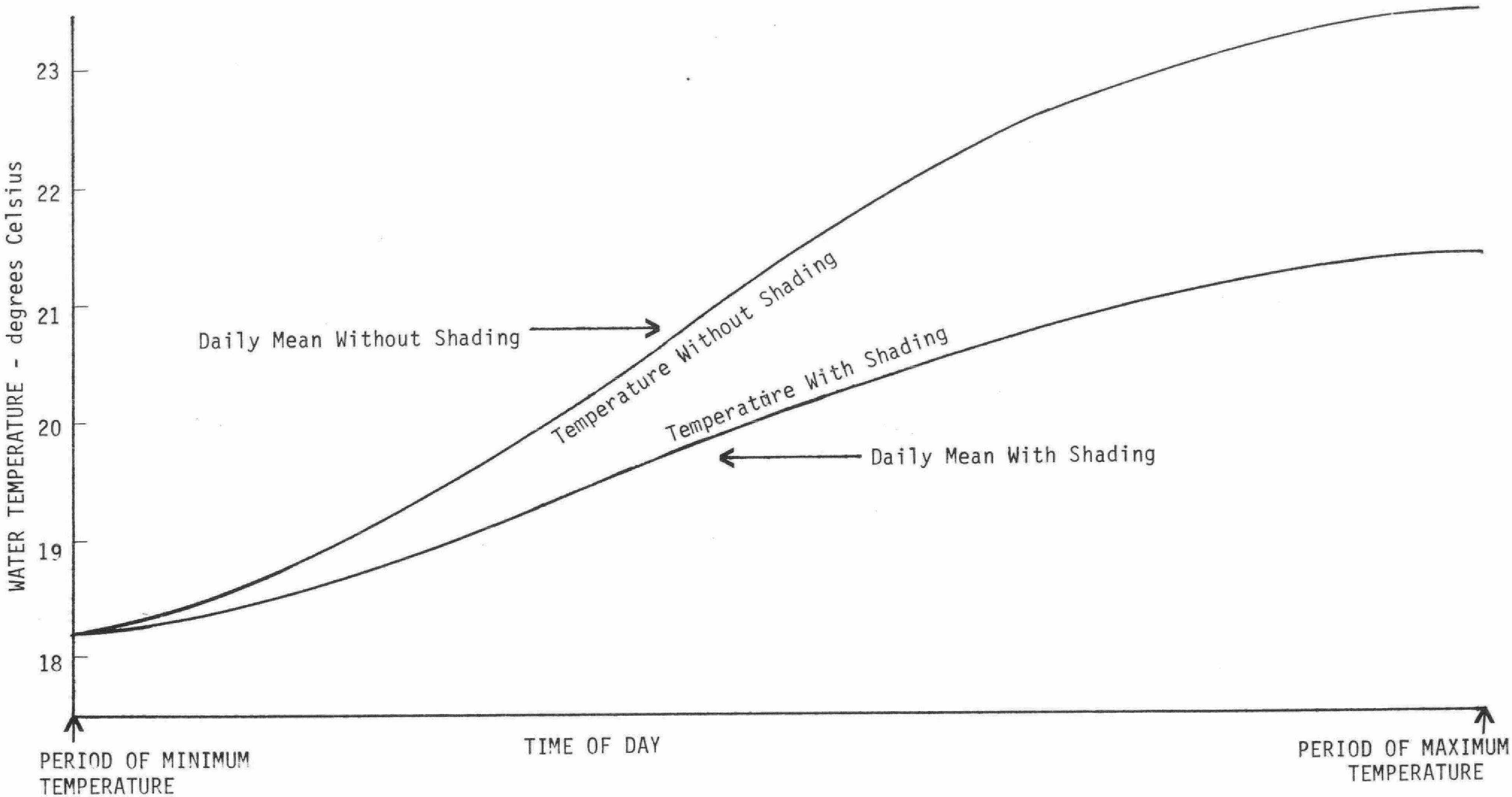

FIGURE 5: ASSUMED IMPACT OF SHADING ON WATER TEMPERATURE

September (153 days). If this volume is assumed to come entirely from the stream by induction through the stream banks, stream flows would be reduced by 0.054 m^3/s at the mouth or 0.029 m^3/s at the federal monitoring station - GD018 (station 10).

In 1981 this would have represented a 1 to 7% decrease in the mean summer flows. The $7Q_{20}$ flow would be reduced by 48%. On the other hand, direct evaporation from the stream should decrease as a result of increased shade. It is difficult to predict the overall impact of these two factors on drought flows.

6. COSTING

Itemized cost data for this planting program are presented in Table 4. Costs, based on 1983 market prices, are expressed as unit costs and costs per kilometer of stream (planting on both banks assumed).

Table 5 outlines the expected yearly cost of shading providing for an assumed 50% tree replacement rate in the first two years. The total planting costs for this shading experiment would be $38,600. Fencing along the pasture lands would increase this figure by $82,000 (Table 4).

Based on 1983 prices, land to be used in this project is valued at less than $6,200/ha (personal communication, Bill Driver, Upper Thames River Conservation Authority). Since the parcels of land to be severed on each farm lot are too small, easements may be required. Without a great deal of farm operator co-operation easement costs could raise total project costs to $250,000. It must be stressed that these costs are preliminary in nature. Factors such as the natural regeneration of willows after ice damage, the need for ground preparation before planting and the possible inclusion of terrestrial habitat enhancement features in the planting program could affect costs but have been ignored here.

7. SUMMARY

Based on the analysis presented above, it is evident that arboreal shading can significantly reduce the amount of light reaching the Avon River. In addition it may also have a notable impact on water temperature and extreme drought flows, although these findings are not conclusive.

TABLE 4: TREE PLANTING COST DATA

Item Description	Unit	Unit Cost	Quantity per km.	Cost/km of Stream (Planting on a 6 m strip both sides)
Trees				
Black willow*	100 trees	$150	953 trees	$ 142.95
Silver maple (15-30 cm)	1000 trees	$175	953 trees	$ 166.78
Cottonwood*	1000 trees	$100	953 trees	$ 95.30
Herbicide-Simazine 6.7 kg/ha	1 kg	$ 30	8.04 kg.	$ 241.20
Rodenticide-Zinc Phosphide 3.6 kg/ha	20 kg	$ 26	4.32 kg	$ 5.62
Labour (1-man day = 8 hrs)	man day	$48		
Planting - 400 trees			2.4 days	$ 115.20
Herbicide - 400 trees			2.4 days	$ 115.20
Rodenticide - 400 trees			2.4 days	$ 115.20
Fences	1 m	$4.10	2000 m	$8200.00

* Unsubsidized cost of trees supplied through Ministry of Natural Resources. The use of cuttings harvested locally would significantly reduce their cost.

TABLE 5: TOTAL COST OF SHADING

	Year	Cost/km	Cost for river (16.5 km)
Trees			
3 species	1	$ 405.	$ 6,700
with 50%	2	203.	3,300
replacement/yr	3	203.	3,300
Herbicide	1	247.	4,100
and	2	247.	4,100
Rodenticide	3	247.	4,100
Labour	1	346.	5,700
	2	288.	4,800
	3	288.	4,800
Total Planting Cost	1	998.	16,500
	2	738.	12,200
	3	738.	12,200
Net Present Value of Total Planting Costs (7% discount rate)		2,300.	38,600
Fencing Costs (10 km, both sides)		8,200	82,000

Black willow, silver maple and poplar have been identified as suitable species to plant. Planting costs for a three-year planting program amount to $38,600. Actual planting would have to be spread over several years however to overcome forestation problems in the flood plain. The cost per kilometer of stream is about $2000. Easements costs and fencing would each add another $8,000 to this. Clearly, cooperation from the land owners along the river is critical to the success of such a scheme.

STRATFORD-AVON RIVER ENVIRONMENTAL MANAGEMENT PROJECT
LIST OF TECHNICAL REPORTS

S-1 Impact of Stratford City Impoundments on Water Quality in the Avon River
S-2 Physical Characteristics of the Avon River
S-3 Water Quality Monitoring of the Avon River - 1980, 1981
S-4 Experimental Efforts to Inject Pure Oxygen into the Avon River
S-5 Experimental Efforts to Aerate the Avon River with Small Instream Dams
S-6 Growth of Aquatic Plants in the Avon River
S-7 Alternative Methods of Reducing Aquatic Plant Growth in the Avon River
S-8 Dispersion of the Stratford Sewage Treatment Plant Effluent into the Avon River
S-9 Avon River Instream Water Quality Modelling
S-10 Fisheries of the Avon River
S-11 Comparison of Avon River Water Quality During Wet and Dry Weather Conditions
S-12 Phosphorus Bioavailability of the Avon River
S-13 A Feasibility Study for Augmenting Avon River Flow by Ground Water
S-14 Experiments to Control Aquatic Plant Growth by Shading
S-15 Design of an Arboreal Shade Project to Control Aquatic Plant Growth

U-1 Urban Pollution Control Strategy for Stratford, Ontario - An Overview
U-2 Inflow/Infiltration Isolation Analysis
U-3 Characterization of Urban Dry Weather Loadings
U-4 Advanced Phosphorus Control at the Stratford WPCP
U-5 Municipal Experience in Inflow Control Through Removal of Household Roof Leaders
U-6 Analysis and Control of Wet Weather Sanitary Flows
U-7 Characterization and Control of Urban Runoff
U-8 Analysis of Disinfection Alternatives

R-1 Agricultural Impacts on the Avon River - An Overview
R-2 Earth Berms and Drop Inlet Structures
R-3 Demonstration of Improved Livestock and Manure Management Techniques in a Swine operation
R-4 Identification of Priority Management Areas in the Avon River
R-5 Occurrence and Control of Soil Erosion and Fluvial Sedimentation in Selected Basins of the Thames River Watershed
R-6 Open Drain Improvement
R-7 Grassed Waterway Demonstration Projects
R-8 The Controlled Access of Livestock to Open Water Courses
R-9 Physical Characteristics and Land Uses of the Avon River Drainage Basin
R-10 Stripcropping Demonstration Project
R-11 Water Quality Monitoring of Agricultural Diffuse Sources
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R-14 Evaluation of Tillage Demonstration Using Sediment Traps
R-15 Statistical Modelling of Instream Phosphorus
R-16 Gully Erosion Control Demonstration Project
R-17 Institutional Framework for the Control of Diffuse Agricultural Sources of Water Pollution
R-18 Cropping-Income Impacts of Management Measures to Control Soil Loss
R-19 An Intensive Water Quality Survey of Stream Cattle Access Sites

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